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Identification of environment friendly tillage implement as a strategy for energy efficiency and mitigation of climate change in semiarid rainfed agro ecosystems

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A B S T R A C T

Agriculture and associated sectors have a significant impact on environment such as GHG emissions, depletion of mineral and fossil resources. Agriculture contributes 25% of global greenhouse gas emissions of which seed bed preparation has a significant share. It contributes 23–44% of total CO_2 emissions due to fossil fuel consumption and soil organic carbon oxidation. Increasing consciousness on environment and food security has created interest towards low-energy agriculture and reduction of greenhouse gas emissions. Hence identification of a primary tillage implement can be a powerful strategy to mitigate the climate change through reduced fuel consumption and greenhouse gas emissions (GHGs) for cleaner agricultural production and to improve the environment quality. Therefore, the present study focuses on identifying the energy efficient and environment friendly primary tillage implement by analyzing the energy and carbon efficiency indicators. The objective of the present study was to assess the effect of commonly used primary and secondary tillage implements in single or in combination for seed bed preparation in developing countries like Cultivator (CV), Cultivator followed by Disc Harrow (CVH), Disc Plough (DP), Disc Plough followed by Disc Harrow (DH), Mould Board Plough (MP), Mould Board Plough followed by Disc Harrow (MPH), Rotovator (RO), Bullock Drawn Plough (BP), Bullock Drawn Harrow (BH), No Tillage (NT) on energy conservation, environment impact and global warming potential. The aim of the study was to identify climate smart primary tillage implement for clean production technology to improve the environmental quality in semi-arid rainfed conditions of India. CV, MP and RO recorded higher soil based greenhouse gas emissions. NT and Animal Drawn Implements recorded lower soil-based greenhouse gas emissions. Fuel consumption-based CO_2 emissions for preparatory cultivation and sowing were found to be 92, 81, 60, 60 and 40 per cent lower in BP, BH, tractor drawn CV, DH, RO respectively as compared to MPH RO and MPH f recorded higher total CO_2 equivalents over other tillage implements used in the present experiment. Among the different methods, reduced tillage with DH recorded higher energy use efficiency and carbon efficiency. Our study indicated that primary tillage implement with minimum soil disturbance and lower number of operations is an ideal environment friendly practice for mitigation of climate change as it recorded low Global Warming Potential (GWP), energy and cost of cultivation with minimum yield reduction.

1. Introduction

The important environmental concern in 21st century is global warming due to increase in greenhouse gasses (GHGs) concentration in the atmosphere. The indiscriminate use of inputs to obtain higher production leads to higher environmental pollution, depletion of resources, higher energy consumption and increasing concentration of (GHGs) emissions. Among the three GHGs CO_2

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emissions are major contributors (Villoria-Sáez et al., 2016). Of the total anthropogenic emissions 25% GHGs emissions are from agriculture and associated land use changes (Paustian et al., 2016). The soils account for the majority (50% CO_2 and 37% mainly as N_2O and CH_4) of agricultural emissions (Lu X et al., 2018; Jug et al., 2018). The higher impact of agriculture on environment (GHGs) emissions and energy consumption per hectare is related to improved crop management practices (Budzyński et al., 2015). The improved agro techniques use highly mechanized technological operations which are both energy intensive and cause environmental pollution. The high energy consumption by agricultural machines and chemical fertilizers has increased GHGs emissions rapidly (from 2919.51 CO_2-eq. in 1990–8993.46 CO_2-eq. in 2014) (Wu et al., 2017). Fossil fuel consumption for tillage (land preparation), exhaust gas emissions from tractors engines and oxidation of soil organic carbon in arable crop production system have major impact on environment as they cause 30–44% CO_2 emissions (Naujokienė et al., 2018). In fact, conventional deep soil tillage MP, DP or RO account for 29–59% of the diesel fuel used for agriculture and requires higher energy input (Sarauskis et al., 2018). Hence, reduced tillage with appropriate tillage implement is an efficient strategy for mitigation of climate changes (Qi et al., 2018) as it reduces energy consumption (Kusek et al., 2016), prevents soil degradation and reduces labor and fuel costs. Earlier studies have revealed that tillage consumes 29–59% of diesel fuel and is a hotspot process for GHGs emissions (Orozco et al., 2016; Pratibha et al., 2015; Hamzei and Seyyedi, 2016). Furthermore, tillage consumes more than 50% energy with greater impact on the overall environmental burden (Patil et al., 2016). Fuel and energy consumption during primary tillage depends on tractor engine power, working width of tillage equipment, number of soil-working tools, distance between them, weight of the implement etc. Tillage is not only energy intensive but also causes short-term modifications in soil microbial community and soil structure which in turn affect the oxidation of organic matter (Buysse et al., 2017), nutrient dynamics of soil like N mineralization and denitrification within hours after soil disturbance. This nutrient cycling is linked to emissions and consumption of important GHGs like CO_2, N_2O and CH_4 (Ferrara et al., 2017; Miaomiao et al., 2017). The complex interactions between climatic factors, biological, chemical and physical properties of soil (Ahmed et al., 2018) are primarily responsible for release and uptake of CH_4 and N_2O. The change in the physical and chemical properties of the soil is primarily due to tillage operations. Hence, tillage apart from CO_2 emissions also contributes to other GHG emissions (Yadav et al., 2018). Soil based CO_2 emissions increase with increase in the depth of ploughing (Buragienė et al., 2015). The increase in working depth of ploughing from 100 mm to 200 mm increases CO_2 emissions from tractors for up to 13% (Šarauskis et al., 2016). Apart from this, the depth of tillage, soil disturbance volume and the size of voids (which permit air diffusion into the soil) are two crucial factors in determining the CO_2 efflux due to tillage (Yu and Adrian, 2017). The depth of tillage and intensity of the soil disturbance depend on the equipment used. For example, tillage implements like the roto tiller which is equipped with rotary powered blades churns the aggregates intensely whereas non-powered disc mechanisms cause less aggregate breakdown but may be efficient in inverting the soil profile (Miller et al., 2015). Mouldboard plough causes a short-lived but very high CO_2 efflux (Yu and Adrian, 2017) as the soils ploughed with mouldboard plough have more soil surface area, high surface roughness and void fraction as compared to disc-harrowed soils. Toby et al. (2016) observed significant fuel savings with different combinations of tillage implements or a decrease in tillage intensity. The adoption of reduced depth of ploughing, harrowing and no ploughing is environment friendly since it helps in substantial fuel savings and reduced CO_2 emissions (Vilma et al., 2018). This also reduces the drawbacks of the traditional way of ploughing which results in high energy and fuel consumption. Thus, over the years, it has become important to assess the impact of agricultural operations in general and tillage operations on environment (Bacenetti et al., 2015). Any kind of adjustment that can impact fuel efficiency or that may reduce fuel consumption and CO_2 emissions may result in reduction of energy consumption and environmental pollution, thereby contributing to cleaner production (Prinz et al., 2018). While the benefits of no-tillage or reduced tillage for the GHGs emissions mitigation are a subject of debate, Dey et al. (2018) attributed that no-tillage soil had larger CO_2 emissions as compared to tilled soil. Selection of tillage implement depends on the soil texture, arable crops, soil and climatic conditions (Lovarelli et al., 2017).

Therefore, understanding the effect of different tillage implements on soil GHGs fluxes can help us identify climate smart tillage implement as a mitigation strategy within present climate change context. At present the available information on effect of tillage implement for seed bed preparation is only on short term dynamics (up to 5 h after tillage) of CO_2 emissions. Moreover, most of the available studies are on Life Cycle Assessment (LCA). The studies with different tillage implements in rainfed conditions are still limited. Therefore, while designing environment-friendly rainfed crop production systems, selection of tillage implements for seed bed preparation play a key role since the fuel consumption, soil based GHG emissions in general and the quantity of C lost in the form of CO_2 due to soil tillage are strongly correlated with the degree and volume of soil disturbance (Reinsch, 2018; Ahmed et al., 2018). Hence, there is a need to have studies on soil GHG emissions and fuel consumption-based CO_2 efflux with the use of different primary, secondary and conservation tillage implements to help in the development of new climate protecting tillage implements. We hypothesize that the use of different tillage implements under rainfed conditions will affect energy use, GHG emissions and carbon efficiency after tillage. Therefore, a study was conducted with an objective to assess the mitigation potential (GHG emissions, low carbon foot print) and energy conservation of different tractor and animal drawn implements which are mostly used for seed bed preparation under rainfed alfisols of developing countries. This study is essential for selecting the most climate friendly and energy efficient tillage implements.

2. Methodology

2.1. Study site and soil type

A study was conducted at ICAR-Central Research Institute for Dryland Agriculture (ICAR - CRIDA), farm located at Hayathnagar (HRF), Hyderabad in semi-arid regions of South India (17° 23'N latitude 78° 29' E longitude), altitude 540 m above mean sea level). Average seasonal annual maximum and minimum temperature was 32 °C and 20 °C respectively during the experimental period. The soil at the study site is Typic Haplustalf, soil order alfisol and Hayathnagar series. The textural composition of the study site is 73.8% sand, 8.2% silt and 18% clay. The experimental soil has 3.4 g kg^{-1}, 150.8 kg ha^{-1}, 14.59 kg ha^{-1}, 180.2 kg ha^{-1} of organic carbon, available N ($KMnO_4$ extractable N contents), P and K respectively. The tillage experiment was conducted on untilled soil after harvest of castor crop.

2.2. Tillage treatments

The study was conducted with 10 tillage treatments replicated in 3 blocks in Randomized Block Design (RBD). Each experimental plot size was 40 m long and 15 m wide. Each plot was separated by

3 m gap for the movement of the tractor. The replications were divided by 5 m wide buffer strips. The tillage treatments were disc plough (DP), disc plough followed by disc harrow (DPH), cultivator (CV), cultivator followed by disc harrow (CVH), mould board plough (MP), mould board plough followed by disc harrow (MPH), rotovator (RO), bullock drawn plough (BP), bullock drawn harrow (BH) and no tillage (NT). The detail specifications of implements used in the treatments is given in Table 1. After preparatory cultivation a deep-rooted pigeon pea was sown to study the effect of primary tillage treatments on crop productivity. The experiment was repeated twice in a year for two years. In the second year, apart from experiment conducted on experimental farm, it was also conducted in 5 farmers' fields (producer fields) with similar soil type and climatic conditions. The results of two years for experimental farm and that of farmers' farms did not differ significantly; hence, the pooled analysis of the data was presented in this study.

2.3. Fuel consumption and fuel energy

Quantity of diesel fuel used by 48 HP two-wheel drive tractor during land preparation with different tillage implements tested was measured in each treatment by filling the tank of the tractor up to the brim with diesel before starting tillage operations with DP, CV, MP, MPH, CVH, DPH, DH and RO. After ploughing in each treatment, tank was refilled and the refilling quantity was recorded with 1000 ml graduated cylinder. Time taken for ploughung in each treatment was recorded. Fuel consumption per hour per hectare was calculated and time taken was calculated using following formula by Akbarnia (2014). Values were then converted into liter ha^{-1} and hour ha^{-1} respectively. Fuel consumption of different tillage operation with different tractor drawn tillage implements was done in three replications.

$$Fc = Fu / A \quad (1)$$

Where, Fc is fuel consumption (l ha^{-1}), Fu is fuel used per unit area (l), A is Area of plot (ha).

2.4. Soil disturbance and bulk density

To measure the depth, two pegs were driven on the either sides of furrow into the soil. The two pegs were then connected using a string whose level was maintained using spilt level. The actual depth of tillage was obtained by subtracting the vertical distance between the string and ground using a steel tape. Depth was measured randomly in 10 replications in each treatment. Width of operation (W) in each treatment was estimated by measuring the horizontal distance of soil cut by implements with the help of measuring tape. It was determined by measuring distance from furrow wall of first furrow to wall of last furrow.

Then the soil volume (m^3hr^{-1}) disturbed was calculated by multiplying the field capacity with the depth of cut (Dabhi et al., 2016).

$$V = 10000SD \quad (2)$$

Where, V is Soil volume disturbed (m^3hr^{-1}), S is effective field capacity (ha hr^{-1}), D is Depth of cut (m). Effective field capacity was measured as given by RNAM (1995).

$$S = A/T_p + T_t \quad (3)$$

Where, S is effective field capacity (ha hr^{-1}), A is area tilled (ha), T_p and T_t are productive time (h) and non-productive time (h) respectively.

Soil bulk density was estimated at 0–10 cm, 10–20 cm and 20–30 cm depth by ring core method (Gatea et al., 2018). In order to observe the change in bulk density, it was measured before and after tillage for all treatments. Five undisturbed soil samples from each treatment per replication were collected randomly at different depths of the soil with cylindrical cores. Samples were collected with soil probe and excess soil was removed by scraping the ring level with a blade or knife. Fresh and dry weight of the soil samples were recorded after drying the samples in oven at 105 °C temperature for 24 h. Soil bulk density was estimated from oven dried undisturbed cores as mass per volume of oven dried soil.

$$Db = W/V \quad (4)$$

Where, Db is bulk density of soil (g cm^{-3}), W is weight of moist soil collected (g), V is volume of core (cm^3). Soil moisture was calculated by determining mass of wet and dry samples. The volumetric moisture content was calculated from the bulk density and gravimetric moisture content.

2.5. Carbon input

2.5.1. Carbon emissions and global warming potential (GWP)

In the present study, total CO_2 equivalent emissions included the direct emissions (GHG emissions from soil after tillage) and the indirect emissions (GHG emissions from different inputs like diesel fuel, chemical fertilizer and biocide) converted into carbon emissions (kg CE) by multiplying with a factor of 12/44.

2.5.1.1. Indirect emissions. GWP is total set of GHG emissions (CO_2, N_2O and CH_4) produced directly and indirectly in crop production. They were converted into CO_2 equivalent by using global warming potential equivalent factors of 1, 298 and 34 for CO_2, N_2O and CH_4 respectively.

Indirect emissions in terms of CO_2 equivalent was estimated by considering GHG emissions from farm operations (tillage, herbicide application, insecticide, planting and fertilizer application, harvest)

Table 1
Technical specifications of tillage implements.

Implements	Abbreviation	Specifications	Working width (cm)	Depth (cm)	Mass (kg)	Economic life (h)
Cultivator	CV	6 tyne cultivator	150	10	200	2000
Disc harrow	DH	Disc harrow with 12 discs	138	10	390	2000
Disc plough	DP	Disc plough with 3 discs. The disc angle and tilt angle were kept as 42^0 and 15^0.	90	15–20	300	2000
Mould Board plough	MBP	A 2 bottom mould board plough was used	75	20–25	275	2000
Rotovator	R	Rotovator with 42 l- shaped blades was used	170	10	310	2000
Bullock drawn plough (BP)	BP	A bullock drawn local plough	13	8	12	1000
Bullock drawn harrow	BPH	A bullock drawn harrow was used	50	8	25	1000
Tractor			–	–	1650	10,000

and the production of fertilizer and seeds (input GHG flux). A boundary was set by including the emissions from the manufacture, transportation, storage and delivery of crop inputs (for example, fertilizers and pesticides) to harvest crops. The amount of GHG emissions in terms of CO_2 equivalent associated with agronomic inputs and farm operations was estimated by multiplying the input (diesel fuel, chemical fertilizer and biocide) with its corresponding emission coefficient (Jianjian and Zhang, 2018; Blasi et al., 2016). CO_2 emission from usage of fossil fuel by different tractor based primary tillage implements was calculated by using a standard conversion factor 2.68 kg CO_2 of fuel (WRI).

GWP = Soil based CO_2 emissions + CO_2 equivalents diesel fuel + CO_2 equivalents N_2O + CO_2 equivalents CH_4.

2.5.1.2. Direct GHG emissions. The direct source of GHG emissions considered in the study was soil-based CO_2, N_2O and CH_4 emissions. CO_2 flux generally starts within 5 min after the tillage pass and continues hence in-situ soil respiration was estimated with EGM 4 soil CO_2 flux system (PP Systems, Hitchin, UK). This instrument has an integral CO_2 analyzer, H_2O sensor, soil respiration chamber, and soil temperature probe and is connected to a data logger (Yasutake et al., 2014). This EGM chamber has the capacity to estimate CO_2 flux from 0 to 9.99 g CO_2 C m^{-2} h^{-1}. A soil CO_2 flux chamber of 10 cm diameter and 12 cm height was fixed in the soil up to 1.5 cm depth in to randomly selected locations. The EGM was placed on the flux chamber to measure the CO_2 flux. The CO_2 flux was recorded 5, 30 and 60 min after tillage in each plot on the first day since the emissions start 5 min after tillage. Subsequent measurements were made on 1, 2, 3, 6, 7, 10 and 15 days after tillage. At the end of which the soil CO_2 fluxes was near equilibrium. Three measurements were recorded in each plot within 90 s. Soil net CO_2 efflux measurements are in m mol m^{-2} s^{-1}. Values of daily soil CO_2 efflux are expressed in g CO_2 m^{-2} and were converted to kg CO_2 ha^{-1}.

N_2O and CH_4 fluxes were measured 24 h after tillage with rectangular aluminium insulated static vented chambers (80 cm × 40 cm x 10 cm) of cross-sectional area of 0.32 m^2 (Weiler et al., 2017). The vented chamber was a two-piece system with an anchor and a cover. The chambers were placed on to anchors which were welded with a water channel. The anchors were placed into soil to a depth of 10 cm. The CO_2, N_2O and CH_4 emissions were recorded from 24 h after tillage till 15 days after the tillage until when the emissions from all the treatments were almost same. The gas samples were collected with syringes between 9 and 12 a.m. These samples were subsequently analyzed using a fully automated GC fitted with electron capture (ECD) detector, thermal conductivity and flame ionization (Wolff et al., 2018) (Model 4200; Bruker Palo Alto, CA). Cumulative seasonal GHG fluxes (CO_2, N_2O and CH_4) were calculated from the linear or nonlinear increase in concentration (selected according to the emission pattern) in the chamber headspace with time (Weiler et al., 2017).

2.6. Energy consumption

The energy input (energy consumption) was computed by considering all direct and indirect energy inputs. The direct and indirect energy coefficients used were obtained from the reported values in different studies (Parihar et al., 2018; Ozturk, 2006; Mittal and Dhawan, 1988). In the present energy estimate of manual labor and bullock power, input was considered unlike the other studies of developed countries, since significant amount of human labor was used for land preparation like in any developing country and wherein the energy coefficient of human labor corresponds to the biochemical energy potentially consumed by a person (Yuan and Peng, 2017). The total energy input (EIC_t MJ ha^{-1}) of different preparatory cultivation methods was computed by using direct energy (amount of fossil fuel used for the tillage by the tractor) and the indirect energy inputs. The total energy inputs were estimated by the following formula:

$$EIC_t = EI_d + EI_{id} \tag{5}$$

Where, EIC_t is total energy (MJ ha^{-1}), EI_d is direct energy (MJ ha^{-1}) and EI_{id} is indirect energy (MJha^{-1}).

$$EI_d = EI_f + EI_h + EI_b \tag{6}$$

The total direct energy inputs are the fuel and oil consumed by the tractor and different machinery used for preparatory (the direct energy input for cultivation) cultivation and total amount of energy consumed for human labor and bullock pair.

Human labor energy input is the energy consumed by the human body during the preparatory cultivation with different implements.

$$EI_h = (NL \text{ x } WH/CA) \text{ x } EEL \tag{7}$$

Where, EI_h is human energy input, NL is number of labors (person), WH is working hours (h), CA is cultivated area (ha) and EEL is energy equivalent of human labor (MJh^{-1}) during different operations (preparatory cultivation, sowing, fertilizer application etc.).

The fuel energy for unit cultivation area (EI_f in MJ ha^{-1}) in land preparation (ha) is estimated with the quantity of fuel consumed by the tractor and energy content of diesel fuel.

$$EI_f = mf \text{ X } Ec \tag{8}$$

Where, mf is the diesel fuel consumption of the tractor per area (l ha^{-1}), Ec is the energy content of diesel fuel. The energy content adopted for diesel fuel and oil is 56.31 MJl^{-1} for diesel and oil together.

The indirect energy inputs in the present experiments is energy consumed for manufacturing of agricultural tools/machineries (tillage implements, sprayers etc) used in the experiment and production of seed and fertilizer. Therefore

$$EIC_{ind} = Ei_m + EI_s + EI_f + EI_p + EI_H \tag{9}$$

where, EIC_{ind} is indirect energy (MJ ha^{-1}), EI_m is the indirect energy consumption for the usage of tillage, inter-cultivation implements and sprayer for pesticide and herbicide application per field (MJ ha^{-1}), EI_s is seed production energy input per cultivated area (MJ ha^{-1}) and EI_f is the energy input used for production of fertilizers applied, EI_p is energy input for production of pesticide applied and EI_H is energy used for the production of herbicide applied.

The indirect energy inputs of agricultural tools/machineries is estimated by using equation (Canakci, 2010)

$$ME = G * MP/ TC_{ef} \tag{10}$$

Where 'ME' is the energy use of machine (MJ ha^{-1}), 'G' the weight of machine (kg), 'MP' is the energy use in the machine manufacturing MJ kg^{-1}), 'T' the economic life of machinery (h) and 'C_{ef}' the effective field capacity (ha h^{-1}).

2.7. Energy output and carbon output

Seed yield of pigeon pea was obtained by excluding boarder plants and harvesting plants only in net plot. Seed and stalk samples were oven dried for 48 h at 65 °C and the sample weights were recorded. The energy output of seed and stalk of pigeon pea for each treatment was calculated by multiplying the total grain and biomass yield (kg ha^{-1}) with energy equivalent.

$$EOC_t.\ MJha^{-1} = EO_{ps} + EO_s = (Y_{ps}.E_{ps}) + (Y_s\ Es.) \tag{11}$$

Where, EO_{ps} is the energy output of pigeon pea seed (MJ ha^{-1}), EO_s is the energy output of stalk (MJ ha^{-1}), Y_{ps} is the yield of the main (seed) product (kg ha^{-1}), E_s is the energy equivalent of the main (seed) product (MJ kg^{-1}), Y_s is the yield of the stalk product (kg ha^{-1}) and Es is the energy equivalent of the subsidiary (straw) product (MJ kg^{-1}). For the calculation of the energy outputs in pigeon pea cultivation, the energy equivalents of pigeon pea seed and stalk (Eps and Es) considered was 25 MJ $kg^{-1}$and 10 MJ kg^{-1}, respectively. Total carbon output was estimated as the sum of the carbon equivalent of grain and straw biomass produced by the crop. The carbon equivalent was estimated by multiplying the total biomass with 0.4.

2.8. Carbon and energy efficiency indicators

In the current context the environmental impact of different tillage treatments can be assessed by estimating the carbon efficiency (CE) (Jianjian and Zhang, 2018) and energy use efficiency (EUE).

All the GHG emissions in CO_2 equivalents were converted to carbon equivalents. The carbon and energy efficiency were estimated. Carbon efficiency is the ratio of carbon output to carbon input. Energy efficiency is the ratio of energy output and energy input (Pratibha et al., 2015).

2.9. Statistical analysis

The experiment was conducted in randomized block design (RBD). The statistical analysis was carried out using proc glm of SAS software version 9.2. Tukey's studentized range test (HSD) was employed to offer corrections to p-values while doing multiple comparisons. P value less than 0.05 was used as the criteria for rejecting the null hypothesis of equality of means.

3. Results and discussions

3.1. Field capacity and soil volume disturbance

The depth of tillage was significantly influenced by tillage implements. MP (20 cm) and MPH (20 cm) recorded higher depth of ploughing which was followed by DP (15 cm) and DPH (15 cm). BP, BH and CV (8 cm) recorded the lowest depth of tillage (Table 3). Similar findings were reported by Dabhi et al. (2016).

Performance of a tillage implement was assessed through field capacity and soil disturbance. Among the tractor drawn implements lowest field capacity (FC) was recorded in mouldboard plough followed by disc harrow, MPH (0.16 ha h^{-1}) and DPH (0.18 ha h^{-1}). For the tillage operation with MPH, draft requirement by tractor was higher. This high tractor draft requirement lowers the speed of tractor and tillage operation due to which field capacity (FC) is reduced. Thus, lower FC was recorded in MPH in addition to low FC time taken for ploughing is higher DH (0.31 ha h^{-1}) and CV (0.6 ha h^{-1}) (Shah et al., 2016). On the other hand, the draft requirement for DH and CV are low due to shallow depth and small width of ploughing. This resulted in highest FC in these treatments. Hence, the time taken for operation was also lower.

Highest soil volume disturbance was recorded in MP (476 m^3 h^{-1}), DP (469 m^3 h^{-1}) and CV (476 m^3 h^{-1}) (Table 3). These treatments were on par with each other and were significantly higher than the DH, MPH, DPH and CVH. Animal drawn implements recorded the lowest soil volume disturbance (2%). MP and DP recorded higher soil volume disturbance because of higher depth and width of cutting soil. CV recorded higher soil volume disturbance due to higher field capacity (0.6 ha h^{-1}). The results of the present study indicated that the depth of ploughing and field capacity are directly and positively related to the soil volume disturbance (m^3 h^{-1}). Animal drawn implements had lower soil volume disturbance since depth of ploughing and field capacity were low.

Bulk density of soil was estimated in different tillage treatments before and after tillage. The bulk density (BD) not only indicates soil disturbed by various tillage implements but also helps to know the soil strength and thus the resistance to the penetration of tillage implements or plant roots. Bulk density before tillage at 0–10 cm, 10–20 and 20–30 cm depths in all treatments were 1.53, 1.75 and 1.92 g cm^{-3} respectively. At all depths, no tillage recorded highest BD because the soil was undisturbed and not loosened. Tillage implements significantly influenced the BD (Table 3).

Animal drawn implements recorded lowest bulk density at 0–10 cm depth as compared to tractor drawn tillage implements. The higher BD in tractor drawn implements was because of the compaction of soil by the heavy weight tractor and pressing of the soil by wheels. The compaction of the soil resulted in low porosity of the soil. Among the tractor drawn tillage implements CV recorded lowest bulk density and this was followed by rotovator (RO) (Table 3) whereas, MPH, DPH and CVH recorded highest bulk density at all the depths. This higher BD in MPH, DPH and CVH could be attributed to the repeated tractor wheel traffic during second pass of soil manipulation (harrowing) in addition to the initial primary tillage. The results are in line with the findings of Babatunde et al. (2016). The BD in MP, MPH, DP and DPH in 10–20 cm was lower than 0–10 cm and these treatments recorded lowest BD as compared to other tillage implements in the study. Khedkar and Deshmukh (2018) also reported higher bulk density in MP at 0–10 cm depth and lower BD at 10–20 cm. CV, CVH and RO recorded higher bulk density over other treatments. (Kutlu and Adak, 2017). The higher BD at 10–20 cm in CV and RO was because of shallow depth of ploughing with these implements. The lower BD in tillage with implements like MP, MPH, DP and DPH as compared to CV, CVH and RO lower depths is due to breaking, inverting and better pulverization of soil even at deeper depths (Jabro et al., 2016).

3.2. Fuel consumption

Fuel consumption in liters per hectare (l ha^{-1}) is a better indicator of fuel consumption than liters per hour (l hr^{-1}) as it largely compensates for differences in width among the tillage implements and is on the same basis as other inputs for crop production such as fertilizer, which is expressed on a per hectare basis. Fuel consumption and time taken for seed bed preparation is presented in Table 4.

Fuel consumption for land preparation with different tillage implements varied. Among all the tillage treatments, MPH (27 l ha^{-1}) and DPH (25l ha^{-1}) recorded significantly higher fuel consumption as compared to other tillage implements. These implements were followed by MP (19.45 l ha^{-1}), DP (17.92 l ha^{-1}), CVH (16.64 l ha^{-1}) and RO (12.75 l ha^{-1}) (Table 4). CV and DH recorded lowest fuel consumption. A linear relationship was observed

Table 2
Description and units of energy and carbon parameters used in the study.

Parameter	Description	Abreviation	Unit
Direct energy	Diesel + labor + bullock	DE	MJ ha^{-1}
Indirect Direct energy	Machinery + fertilizers + pesticides + seeds	IDE	MJ ha^{-1}
Total Energy Input	Direct energy + Indirect energy	EI	MJ ha^{-1}
energy output	Energy harvested in grain (Grain yield X energy coeffecient	EO	MJ ha^{-1}
energy use effeciency	Total energy output/Energy input	EUE	–
Green house gas emissions	Sum of total CO_2 and N_2O emission	GHG	kg CO_2 eq. ha^{-1}
Global warming potential	Sum of total CO_2 and N_2O emission converted into CO2 eq.	GWP	kg CO_2 eq. ha^{-1}
Carbon Input	Sum of total GHG emission in CO_2 eq.) X 12/44	CI	kg Ceq. ha^{-1}
Carbon output	Total biomass X 0.4	CO	kg Ceq. ha^{-1}
Carbon effeciency	Carbon output/Carbon input	CE	–

Table 3
Effect of different tillage implements on depth of ploughing (cm), field capacity (ha/hr), volume of soil disturbed (m3 hr-1) and bulk density (g cc-1).

Treatments	Depth of ploughing (cm)	Field Capacity (Ha hr^{-1})	Volume of Soil disturbed (m^3 hr^{-1})	Bulk density (g cc^{-1})		
				Depth (cm)		
				0–10	10–20	20–30
CV	8^{d}	0.60	476^{a}	1.38	1.47	1.53
CVH	8^{d}	0.25	202^{c}	1.42	1.66	1.55
DP	15^{b}	0.31	469^{a}	1.52	1.45	1.55
DPH	15^{b}	0.18	277^{b}	1.54	1.43	1.56
MP	20^{a}	0.24	476^{a}	1.46	1.42	1.45
MPH	20^{a}	0.16	312^{b}	1.49	1.44	1.47
RO	10^{c}	0.29	294^{b}	1.43	1.56	1.63
DH	10^{c}	0.31	310	1.42	1.47	1.65
BP	6^{e}	0.05	30^{d}	1.26	1.61	1.68
BH	6^{e}	0.08	50.2^{d}	1.32	1.6	1.72
NT	0	0	0	1.62	1.74	1.74

Means followed by same letter in the superscript are not significantly different at $p = 0.05$.
CV– cultivator; CVH: Cultivator + Disc harrow; DP: Disc plough; DPH: Disc plough + harrow; MP: Mould board plough; MPH: Mould board plough + Disc harrow; RO: Rotovator; DH: Disc harrow; BDP: Bullock drawn plough; BPH; Bullock drawn plough + harrow; NT: no tillage.Rotovator; DH: Disc harrow; BDP: Bullock drawn plough; BDPH; Bullock drawn plough + harrow; NT: no tillage.

between fuel consumption, depth of ploughing and time taken for ploughing (Sarausis et al., 2016, 2018). Highest fuel consumption in MPH, DPH was due to increased number of operations in these two treatments as compared to MP and DP. MPH and DPH were followed by MP and DP. MP and DP have higher draft requirement due to this the time of ploughing increases and resulted in higher fuel consumption. Even though in CV, RO and DH the depth of ploughing is shallow and same but CV (6%) and RO (86.5%) recorded higher fuel consumption than DH. The higher fuel consumption in CV is because CV ploughs the soil on the principle of sliding action. Hence, CV requires higher draft power as it has higher soil frictional force and contact area due to sliding action (Parmar Pravinsinh Raghuvirsinh, 2016). Furthermore, in CV there is a higher depth of cut and more time is required for CV to plough one hectare land than DH (Arshad and Shah, 2016). Whereas the higher fuel consumption in RO as compared to CV is because RO operates on rotating action. The rotary action and shaft rotation causes higher load on tractor's engine which results in more fuel consumption. Besides the higher fuel consumption, the time taken to plough one hectare of area by RO was almost double as compared to CV due to a difference in forward speeds during operation (Dabhi et al., 2016).

3.3. Carbon input

3.3.1. Direct GHG emissions (soil based CO_2 emissions)

Tillage is the primary cause for CO_2 emission during crop production. This CO_2 emission also leads to the depletion of soil organic matter.

CO_2 emissions were recorded 5 min immediately after tillage till 15 days (Fig. 2). The CO_2 emissions were higher immediately after tillage. It increased up to a certain stage and leveled off by 10th day in all the tillage treatments. During the study period, one significant rain (35.2 mm) occurred at 10 days after tillage. Due to this rain event soil respiration rate increased since rewetting of dry soil stimulates microbial and organic carbon mineralization (Shufang et al., 2017; Gu et al., 2018). The CO_2 fluxes after 15 days were not influenced by the tillage implements hence the soil-based emissions after sowing were not considered. Similar observations were reported by Bista et al. (2017). The CO_2 efflux was higher in seed bed preparation with tillage as compared to NT (no tillage). The lower CO_2 emissions in NT were due to soil densification and decrease in the macro pore volume the decrease in macro pore volume space lead to reduction in gaseous exchange (Wang et al., 2017). Whereas the tillage lead to physical disruption of soil, surface roughness, larger voids, this resulted in increase in soil moisture content De Almeida et al. (2018) which helped in higher biological activity and enhanced the oxidation of soil organic matter and CO_2 efflux. The CO_2 emissions from the soils due to different tillage implements has high correlation with the intensity of the soil disruption and the volume of soil disturbed by the tillage implements used (Melland et al., 2017 and Albert et al., 2016) and depth of tillage (Vieira et al., 2018). But in the present study such correlation was observed only up to 24 h after tillage. Thereafter there was no correlation and this is due to reduction in soil moisture (Table 5) (Carranza-Gallego et al., 2018).

Among the different tillage implements MP recorded highest CO_2 efflux (3.04 g m^{-2}) and this was followed by CV (2.85 g m^{-2}) and DP (2.67 g m^{-2}) till 1 h after tillage (Fig. 2). The higher CO_2 emission in MP and CV immediately after tillage was due to short term burst of CO_2 efflux. This immediate short term efflux of CO_2

Table 4
Effect of different tillage implements on Fuel consumption (l ha-1) and time taken for seed bed preperation.

Treatment	Fuel consumption l ha^{-1}			Time taken hr ha^{-1}		
	Primary tillage	Harrowing	Total	Primary tillage	Harrowing	Total
CV	8.4	0	8.4^{d}	1.68	0	1.68^{h}
CVH	8.4	8.24	16.64^{b}	1.68	2.29	3.97^{f}
DP	18.24	0	17.92^{b}	3.2	0	3.2^{g}
DPH	18.24	7.99	25.91^{a}	3.2	2.22	5.42^{d}
MP	19.45	0	19.45^{b}	4.2	0	4.2^{e}
MPH	19.45	7.99	27.44^{a}	4.2	2.22	6.42^{c}
RO	14.89	0	14.89^{c}	3.4	0	$3.4^{\mathbf{d}}$
DH	7.98	0	7.98^{e}	1.9	0	1.9
BP	0	0	0	20	0	20^{a}
BH	0	0	0	11.96	0	11.96^{b}
NT	0	0	0	0	0	0

Means followed by same letter in the superscript are not significantly different at $p = 0.05$.
CV– cultivator; CVH: Cultivator+Disc harrow; DP: Disc plough; DPH: Disc plough+harrow; MP: Mould board plough; MPH: Mould board plough + Disc harrow; RO: Rotovator; DH: Disc harrow; BDP: Bullock drawn plough; BPH; Bullock drawn plough + harrow; NT: no tillage.

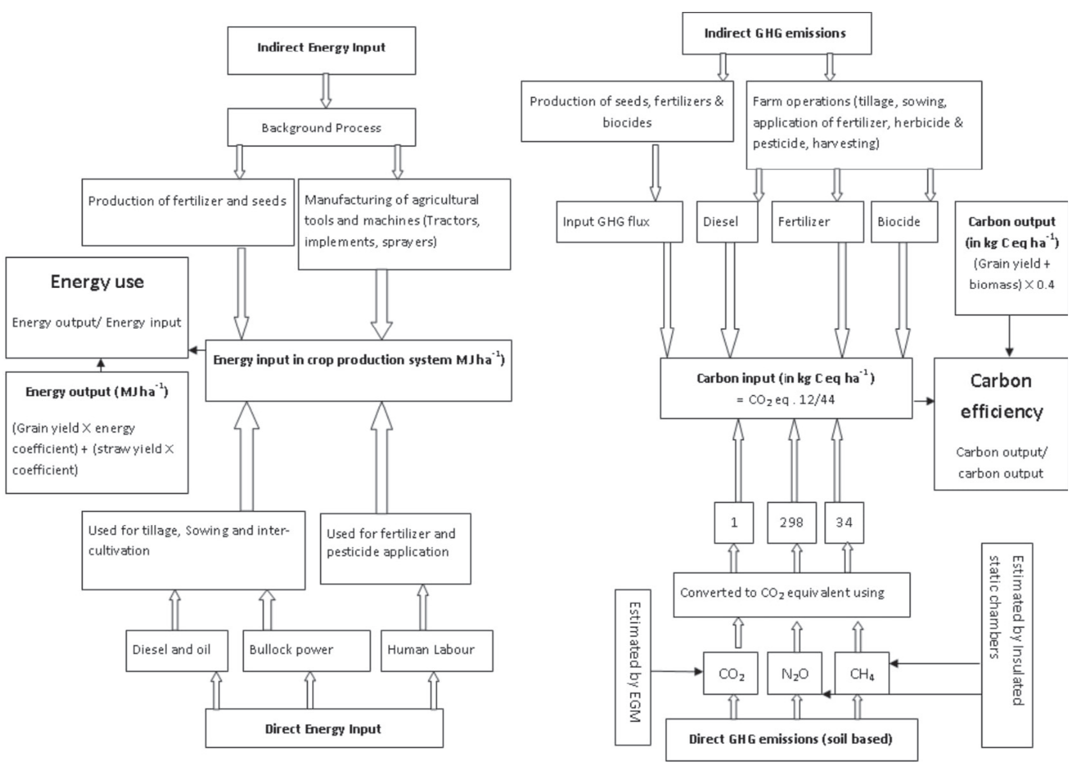

Fig. 1. Flow chart for estimation of energy & carbon efficiency indicators.

after soil tillage was may be due to the 'degassing' due to this phenomena there is physical forcing out of CO_2 from soil due to a sudden decrease in the partial pressure of CO_2 in soil air at the time of tillage (Ferrara et al., 2017). The cumulative soil-based CO_2 emissions 15 days after tillage (DAT) were 55% and 53% higher in CV and RO respectively as compared to NT (Table 5). This higher emissions in CV and RO was due to higher emissions during first 1 h after tillage. Furthermore, RO churns the soil and disintegrates them into finer aggregates which creates a dust mulch due to which the soil evaporation is reduced and more soil moisture is conserved This higher moisture resulted in higher microbial activity and CO_2 emissions (Tang et al., 2015). The cumulative CO_2 emissions from day 1 to day 15 in MP, CV and DP were lower than MPH, CVH and DPH. This is because the soil emissions declined after 24 h (Table 6). When soil was ploughed with MP, DP and CV there was higher soil volume disturbance due to which more soil surface area was exposed to the atmosphere providing for a greater evaporative area resulting into higher soil moisture loss and lower soil moisture content (Büchi et al., 2017). The soil moisture content and CO_2 flux are directly related as per study reported by Gauthier et al. (2017), Almagro et al. (2017). Hence, drier surface soil contributed to lower CO_2 emissions 1 h after tillage and subsequently lowered the CO_2 fluxes in MP, DP and CV. Miaomiao et al. (2017) also observed differential fluxes of CO_2 with different tillage systems. The lowest cumulative CO_2 efflux was recorded in BP (bullock drawn plough) and BH (bullock drawn harrow) and these were on par with NT (no tillage). Low emission in BP and BH may be ascribed to lower microbial activity and poor residue incorporation due to lower soil disturbance resulting in a lower decomposition rate.

3.3.2. N_2O emissions

N_2O emissions from soil from the first day after tillage till 15

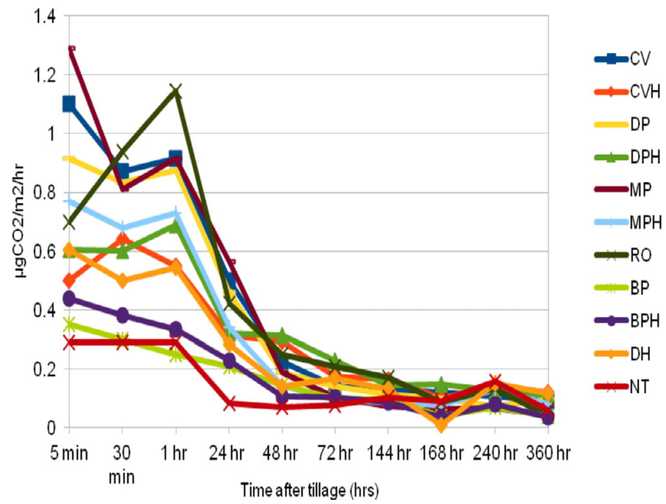

Fig. 2. Influence of tillage implements on CO_2 emissions.

days was recorded (Fig. 3). N_2O emissions were lower initially and increased gradually but at 15 days after tillage the emissions were leveled off in all the treatments (Fig. 3). The N_2O emissions first day after tillage were higher in DP (6.04 µg N m^{-2} hr^{-1}), DPH (5.4 µg N m^{-2} hr^{-1}), MP (4.3 µg N m^{-2} hr^{-1}) and NT (6.4 µg N m^{-2} hr^{-1}). Later from 2nd day after tillage the N_2O emissions decreased in DP and MP by 28% and 25% respectively. Whereas in DPH, CVH and RO N_2O emissions were high till 6 days. Higher total cumulative N_2O emissions were recorded in CVH (61.37 µg N m^{-2} hr^{-1}) and DPH (64.28 µg N m^{-2} hr^{-1}). The emissions in these two treatments were statistically on par but were significantly higher than other tillage treatments. Harrowing after ploughing breaks the clods, mixes the residue and helps in moisture conservation for a longer time, which in turn must have increased dissolved organic nitrogen (Laufer and Koch 2017; Fares et al., 2017). The soil moisture content was higher in harrowing treatments. In general, higher the soil moisture, higher is the N_2O emission (Chen et al., 2018; Hoang et al., 2017), since both the nitrification and denitrification processes are influenced by moisture (Shedayi and Naseer, 2016).

3.3.3. CH_4 emissions

The negative values indicate CH_4 consumption while positive values indicate CH_4 emissions in Fig. 4. The CH_4 emission rates were highly variable among treatments and sampling dates. Methane uptake was observed in all the treatments except in MPH and CV. 1st day after tillage, methane emissions was recorded in CV (1.87 µg C–CH_4 m^{-2} h^{-1}) and MPH (0.47 µg C–CH_4 m^{-2} h^{-1}). Tillage influences gaseous diffusivity and the rate of supply of atmospheric CH_4 as it disturbs CH_4 oxidizing microbes. But in other tillage implements methane absorption was observed. The net consumption of atmospheric CH_4 in different tillage implements indicates that CH_4 oxidizers were active and their activity exceeds that of methanogens when porosity is more. Smith et al. (2018).

Highest methane absorption was observed in animal drawn implements and this was followed by RO and CVH. Higher methane absorption was due to lower depth and intensity of tillage hence the disturbance to the microbes in soil was low. The only known net biological sinks for atmospheric CH_4 are soils where it is oxidized by methanotrophic bacteria, thus less disturbance leads to higher microbial activity in their protected environment.

3.3.4. Global warming potential

The global warming potential (GWP) of different tillage treatments is sum of CO_2 based equivalents of CO_2, N_2O and CH_4 fluxes from soil (Sainju, 2016, 2018) and fuel consumption based CO_2 emissions. The total carbon input in crop production is the sum of soil based GHG emissions, fuel based emissions for tillage, sowing and indirect carbon input (Fig. 1). In addition to soil CO_2 losses, the use of diesel in the tillage operation also results in CO_2 emissions. The CO_2 emission with the use of fossil fuel for tillage with different tractor based tillage implements was estimated by using a standard conversion factor 2.68 kg CO_2 for 1 L of fuel (WRI). MPH and DPH recorded higher fuel consumption (Table 4). The higher fuel consumption in this two treatments was due to the two tractor passes. These treatments were followed by MP and DP. Higher fuel consumption was due to higher depth of tillage and surface volume disturbance. Hence tillage system with fewer operations had low fuel based CO_2 emissions.

The contribution of soil-based CO_2 emissions to GWP was higher as compared to N_2O and CH_4 emissions. All tillage implements recorded higher GWP than the corresponding no-tillage and bullock drawn implements (Table 5). Similar higher GHG emissions with tillage treatments were reported by Soares et al. (2018). CV, RO, MP, DP, DPH and CVH recorded 1599, 1564, 1535, 1516,1495,1409 kg CO_2 eq. ha^{-1} respectively. These treatments were

Table 5
Global warming potential and carbon effeciency of tillage implements for seed bed preperation.

Treatment	Soil based GHG emissions			Tillage & sowing Diesel + Implement energy		Total GHG emissions (Soil based + tillage + sowing + production)	Total C I	CO	CE
	CO_2	N_2O	CH_4	Tillage	Sowing				
	CO_2 equivalents (kg CO2 eq. ha^{-1})						kg C eq. ha^{-1}		
CV	1217^{e}	9.4^{b}	-0.13^{b}	25^{b}	14.72^{a}	1599^{d}	799^{d}	1780^{e}	2.23^{b}
CVH	996^{c}	11.2^{d}	-0.17^{c}	54^{c}	14.72^{a}	1409^{bd}	704^{bc}	1736^{e}	2.46^{c}
DP	1106^{d}	8.4^{b}	-0.23^{d}	54^{c}	14.72^{a}	1516^{cd}	758^{cd}	1480^{c}	1.95^{a}
DPH	1052^{c}	11.8^{e}	-0.11^{b}	84^{d}	14.72^{a}	1495^{cd}	748^{cd}	1680^{d}	2.25^{b}
MP	1120^{d}	8.4^{b}	0.08^{a}	59^{c}	14.72^{a}	1535^{d}	767^{d}	1472^{c}	1.92^{a}
MPH	933^{bc}	8.1^{b}	-0.02^{d}	85^{d}	14.72^{a}	1374^{c}	687^{c}	1650^{d}	2.4^{c}
RO	1161^{d}	10^{c}	-0.1^{a}	45^{c}	14.72^{a}	1564^{d}	782^{d}	1960^{f}	2.51^{d}
DH	912^{b}	7.3^{a}	-0.13^{b}	25^{b}	14.72^{a}	1295^{b}	648^{b}	1700^{de}	2.62^{e}
BP	501^{a}	7.1^{a}	-0.14^{b}	15^{a}	3.8^{b}	860^{a}	430^{a}	1080^{b}	2.51^{d}
BH	548^{a}	8.9^{b}	-0.18	4.5^{a}	3.8^{b}	899^{a}	449^{a}	1120^{b}	2.49^{cd}
NT	543^{a}	8.4^{b}	-0.11^{b}	0^{a}	14.72^{a}	900^{a}	450^{a}	1000^{a}	2.22^{b}

Means followed by same letter in the superscript are not significantly different at p = 0.05.
CV– cultivator; CVH: Cultivator + Disc harrow; DP: Disc plough; DPH: Disc plough + harrow; MP: Mould board plough; MPH: Mould board plough + Disc harrow; RO: Rotovator; DH: Disc harrow; BDP: Bullock drawn plough; BPH; Bullock drawn plough + harrow; NT: no tillage. Other abbreviation details as in Table 2.

Table 6
Relationship between soil volume disturbed and soil moisture content to CO_2 emissions.

Time	Correlation coeffecient	
	Soil volume disturbed Vs CO_2 emissions	Soil moisture vs CO_2 emissions
5 min	0.897	0.78
30	0.87	0.85
1 h	0.86	0.88
1 day	0.89	0.9
2	0.25	0.89
3	0.13	0.91
6	−0.007	0.94
7	0.17	0.93
10	0.35	0.89
15	0.31	0.91
Cumulative	0.98	0.97

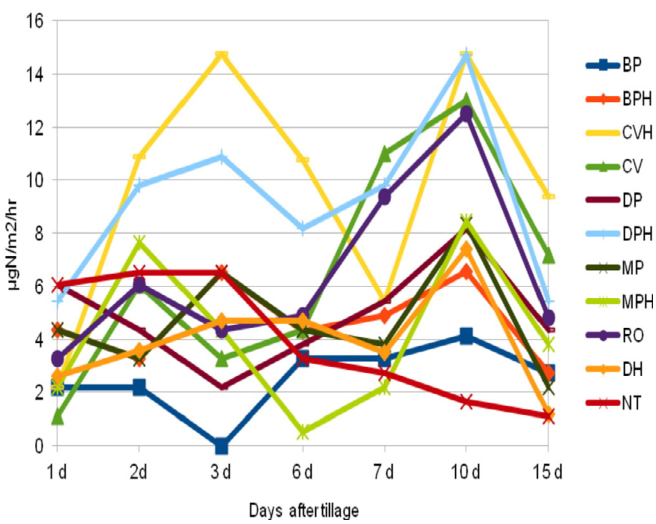

Fig. 3. Influence of tillage implements on N_2O emissions.

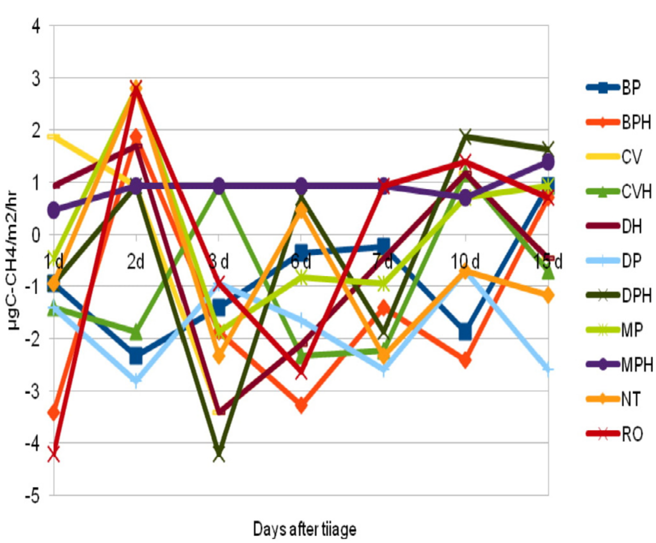

Fig. 4. Influence of tillage implements on CH_4 emissions.

significantly superior over other treatments and were on par with each other. In RO the soil was broken down into finer aggregates which resulted in higher gas exchange and subsequent reactions. This higher emission in these treatments was due to higher soil respiration and N_2O based CO_2 equivalents. Among the tractor drawn implements DH recorded lowest GWP since the fuel consumption and soil-based emissions were lower.

Lowest GWP was recorded in animal drawn implements and it was on par with NT. The lower soil respiration and N_2O based CO_2 emissions in bullock drawn implements were due to low soil volume disturbance and zero fuel consumption-based CO_2 emissions. Hence reduction in tillage can mitigate the GHG emissions (Orozco et al., 2016).

RO recorded highest carbon output (1960 kg C eq ha^{-1}). This was followed by CV (1780 kg C eq ha^{-1}, CVH (1736 kg C eq ha^{-1}) and DH (1700 kg C eq ha^{-1}). The higher carbon output in these treatments was due to higher seed yield. NT (no tillage) and animal drawn implements recorded lowest carbon output.

3.3.5. Energy consumption and energy output

Total energy consumption of different tillage implements was computed by adding the direct and indirect energy inputs. The energy consumption, energy output and energy efficiency of different tillage implements is presented in Table 7. Among different factors of crop production, energy consumption for seed bed preparation is one of the major contributors of energy input (Yadav et al., 2018; Pratibha et al., 2015). Hence identification of proper tillage implement reduces the energy input. The direct energy input for seed bed preparation varied in different tillage implements. The differential energy consumption by the implements in the study was due to difference in fuel consumption by the implements for seed bed preparation and indirect energy used for manufacture, transport, repair and use of machinery. NT recorded no direct energy input for seed bed preparation as there was no diesel consumption. These results are in agreement with the findings of Yadav et al. (2018); Kusek et al. (2016). MPH (1579 MJ ha^{-1}) and DPH (1558 MJ kg^{-1}) recorded highest direct energy consumption. Highest direct energy consumption in MPH and DPH was due to higher fuel consumption. Furthermore, two operations (ploughing and harrowing) were involved in these treatments. MPH and DPH were followed by MP (1096 MJ ha^{-1}), DP (1028 MJ kg^{-1}), and CVH (MJ ha^{-1}). BP and BH recorded lowest energy input for sowing as compared to tractor drawn implements. This was due to fuel consumption in tractor drawn tillage implements whereas in bullock drawn implements there was no fuel consumption. Thus, reduced fossil fuel consumption reduced the energy consumption. The indirect energy input also varied in different tillage treatments. Bullock drawn implements recorded highest indirect energy input for seed bed preparation. This was due to the use of the implements for longer duration required for tillage and sowing. The production energy input did not vary among different treatments since the inputs did not vary among the tillage treatments.

Table 7
Energy consumption and energy use efficiency of different tillage implements for seed bed preperation.

Treatment	Energy input					EO	EUEt
	Direct energy		IDE		Total		
	Seed bed preperation	Sowing	Field preperation to sowing	Production			
MJ/ha							
CV	474[b]	225[b]	90[ab]	3711[a]	4500[c]	61750[d]	13.72[c]
CVH	997[d]	225[b]	116[bc]	3711[a]	5049[c]	59900[d]	11.86[b]
DP	1028[de]	225[b]	129[b]	3711[a]	5093[c]	50500[c]	9.92[a]
DPH	1558[f]	225[b]	154[c]	3711[a]	5649[d]	58500[d]	10.36[a]
MP	1097[de]	225[b]	152[c]	3711[a]	5184[c]	50300[c]	9.7[a]
MPH	1570[f]	225[b]	175	3902[a]	5872[d]	58125[d]	9.89[a]
RO	840[c]	225[b]	122[b]	3904[a]	5090[c]	67000[f]	13.16[c]
DH	450[b]	225[b]	95[ab]	3711[a]	4481[c]	58250[d]	12.99[c]
BP	212[a]	111[a]	370[c]	3557[a]	4135[b]	35875[b]	8.64[a]
BH	169[a]	111[a]	226[c]	3607[a]	4000[b]	37000[b]	9.22[a]
NT	0[a]	234	57[a]	3483[a]	3775[a]	32500[a]	8.6[a]

Means followed by same letter in the superscript are not significantly different at $p = 0.05$.
CV– cultivator; CVH: Cultivator + Disc harrow; DP: Disc plough; DPH: Disc plough + harrow; MP: Mould board plough; MPH: Mould board plough + Disc harrow; RO: Rotovator; DH: Disc harrow; BDP: Bullock drawn plough; BPH; Bullock drawn plough + harrow; NT: no tillage. Other abbreviation details as in Table 2.

Total energy consumption varied among different treatments. No tillage recorded lowest energy consumption. This was followed by bullock drawn implements. Highest energy consumption was recorded in MPH (5872 MJ ha^{-1}) and DPH (5649 MJ ha^{-1}). This higher energy input was due to more diesel fuel consumption. No tillage treatment recorded lowest energy output (32500 MJ ha^{-1}) whereas RO recorded highest energy output and this was followed by cultivator, DH, CVH and CV.

3.3.6. Carbon and energy efficiency indicators

DH (2.62) recorded highest carbon efficiency. This was followed by RO, BH and CVH. The higher carbon efficiency in DH was due to low carbon input and higher carbon output. The lowest carbon efficiency was recorded in MP (1.92) and DP (1.95). This low carbon efficiency was due to higher carbon input and lower carbon output.

The energy efficiency was higher in CV, RO and DH and these treatments were significantly on par with each other and were significantly superior over other implements used for seed bed preparation. The high EUE (energy use efficiency) was due to low energy input and higher energy output in these treatments. Even though the energy consumption was higher under RO the energy output also was high. The low EUE was observed in bullock drawn implements and DP.

4. Conclusions

In recent times, agriculture has become energy intensive and has great impact on the environment. Tillage is a major contributor towards energy consumption and carbon input in rainfed agriculture. Hence, the attention on the energy consumption and environmental issues of use of tillage implement has increased tremendously. Therefore, in the present context choice of suitable tillage implement is crucial, as it can decrease the negative effects of agriculture on the environment by reducing GHG emissions, energy input along with the reduction in cost of cultivation. The present study has revealed that the tillage implements and depth of the tillage influences the soil physical properties, energy consumption, GHG emissions, and GWP and carbon efficiency. RO, CV and DPH recorded higher greenhouse gas (GHG) emissions and GWP (global warming potential), whereas animal drawn implements recorded lower GHG emissions and energy consumption. Even though the GHG emissions and GWP were low in animal drawn equipment, these implements are not recommended due to decreasing animal power because of their higher feeding expenditure and labor cost against their utilization. The results suggest that the seed bed preparation with disc harrow in rainfed alfisols has minimum soil disturbance, energy input, CO_2 fluxes, higher energy use efficiency as well as carbon efficiency.

The practical implication of the present work is that NT (no tillage) and shallow tillage in seed bed preparation with implements like disc harrow in rainfed sandy loam soils is a way to reduce the impact of seed bed preparation and the crop production on environment in rainfed agriculture. Even though no tillage has lower environment impact, the energy use and carbon efficiency were low. Thus, shallow tillage with disc harrow in seed bed preparation has low fossil fuel consumption, high energy use and carbon efficiency. Furthermore, this implement helps in climate friendly tillage practice in addition to reduced environment impact. Disc harrow may help in substantial energy savings.

Overall, the findings of the study indicate the need for promotion of reduced tillage or shallow tillage with disc harrow in rainfed alfisols of semi-arid regions for reducing energy consumption, mitigation of GHG emissions and increasing carbon efficiency. To the best of our knowledge this study is the first one on assessing the impact of different tillage implements used for seed-bed preparation on environmental impact and cleaner production. In the study both environment impact and crop productivity was assessed.

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